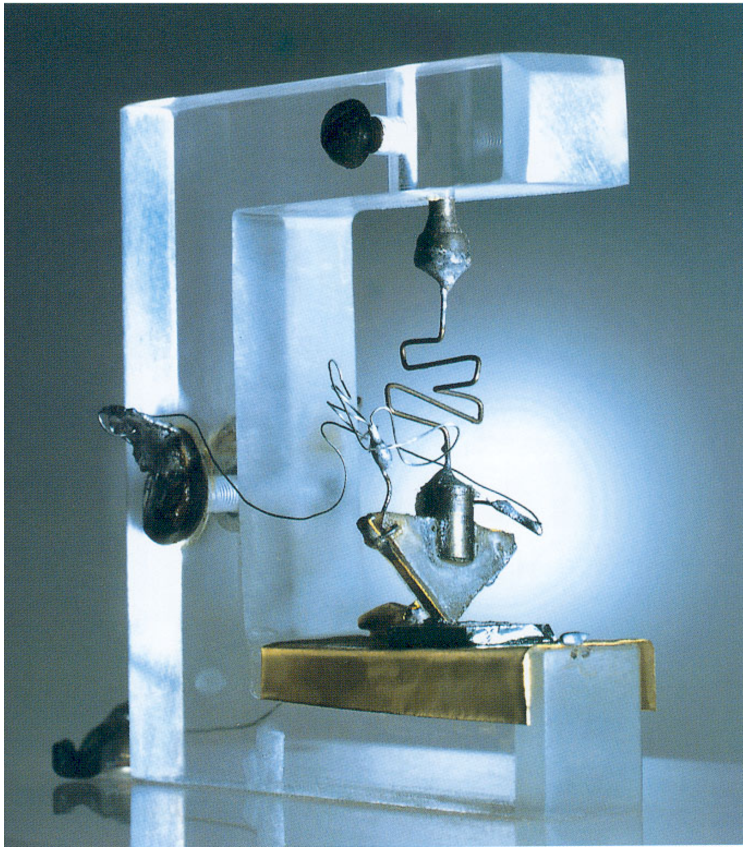
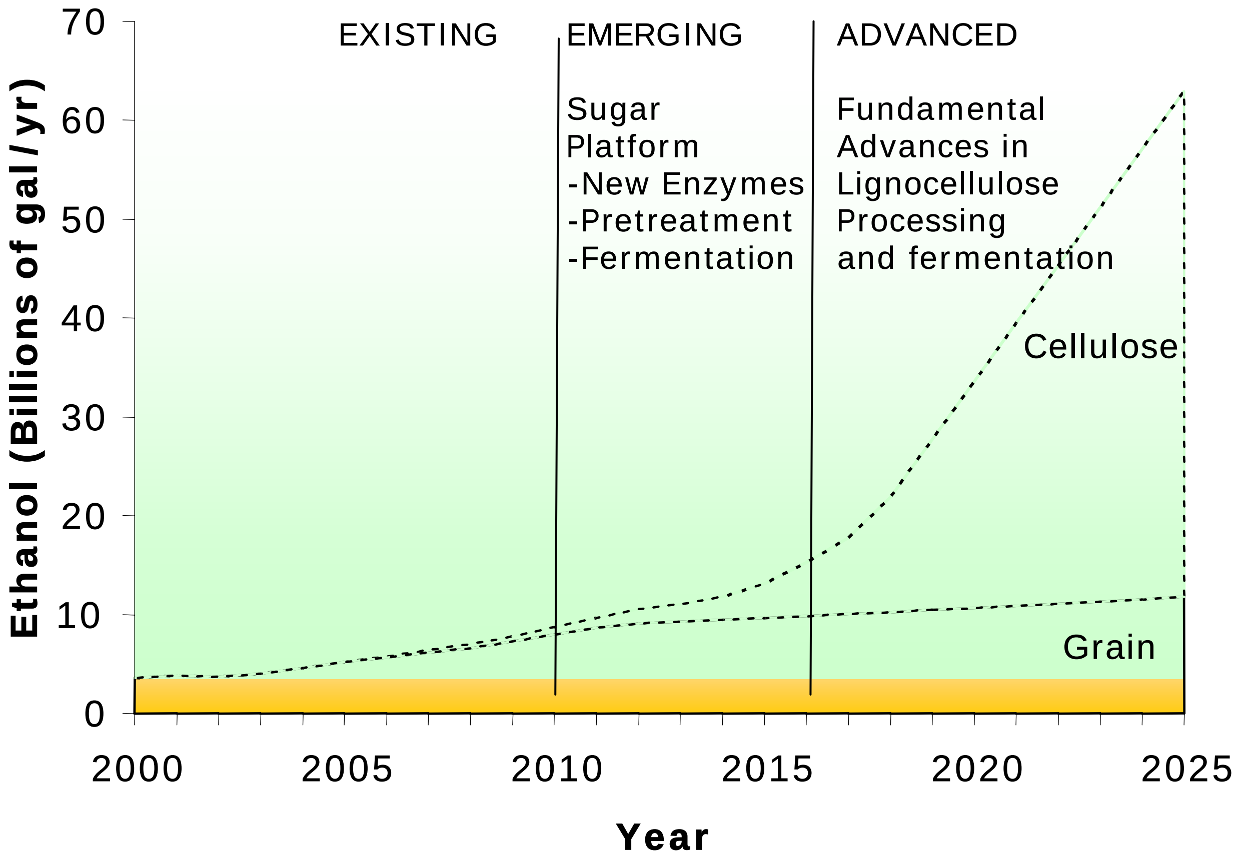
Development of Cellulosic Biofuels



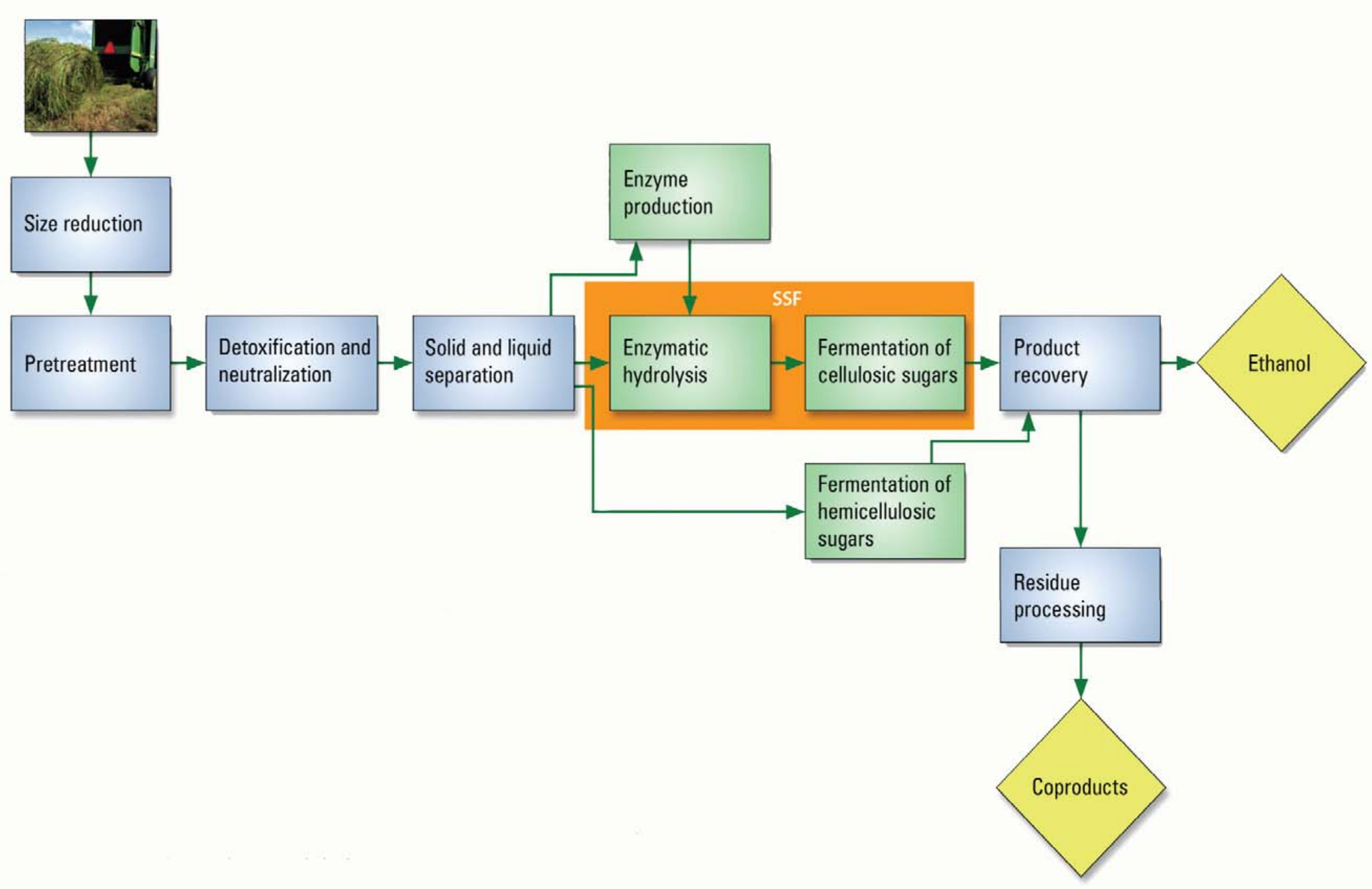
Chris Somerville
Carnegie Institution, Stanford University, Lawrence Berkeley National Lab

A DOE Ethanol Vision



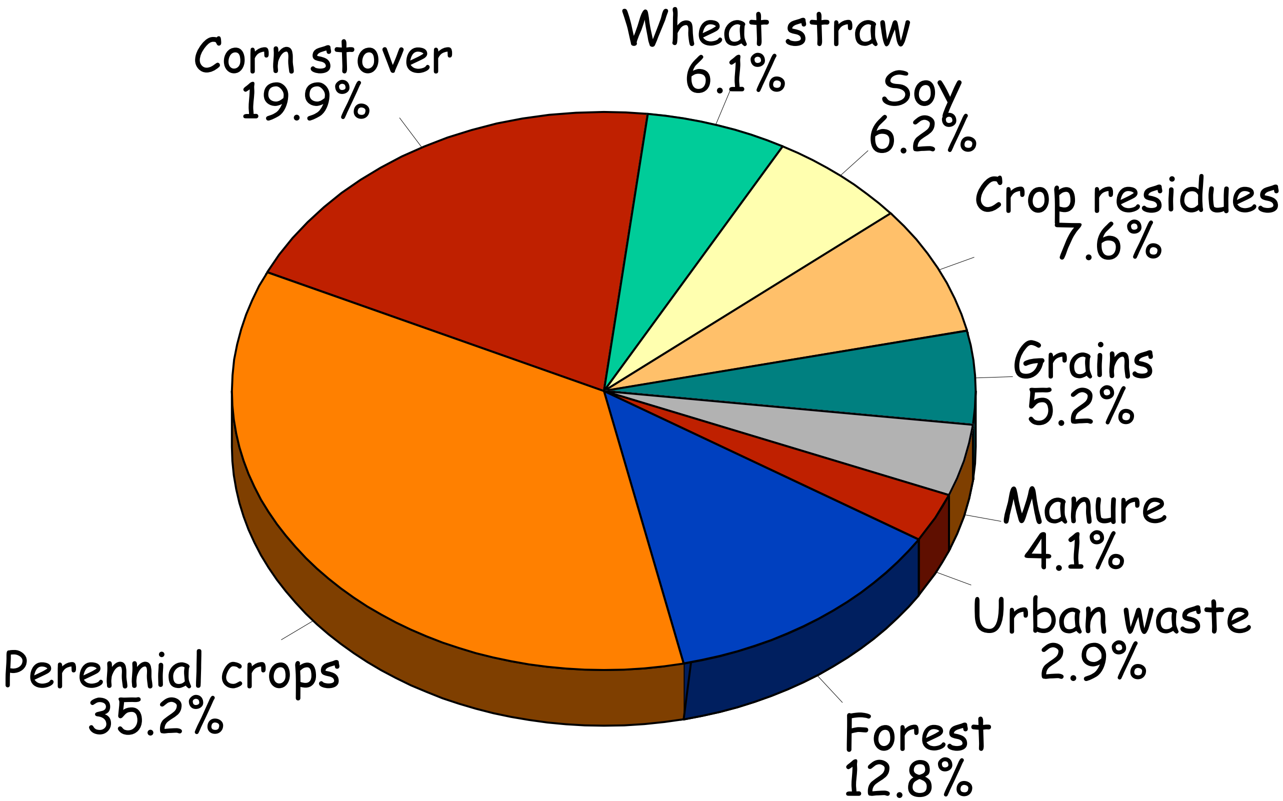
Modified from Richard Bain, NREL

Steps in cellulosic ethanol production



From: Breaking the Biological Barriers to Cellulosic Ethanol

US Biomass inventory = 1.3 billion tons



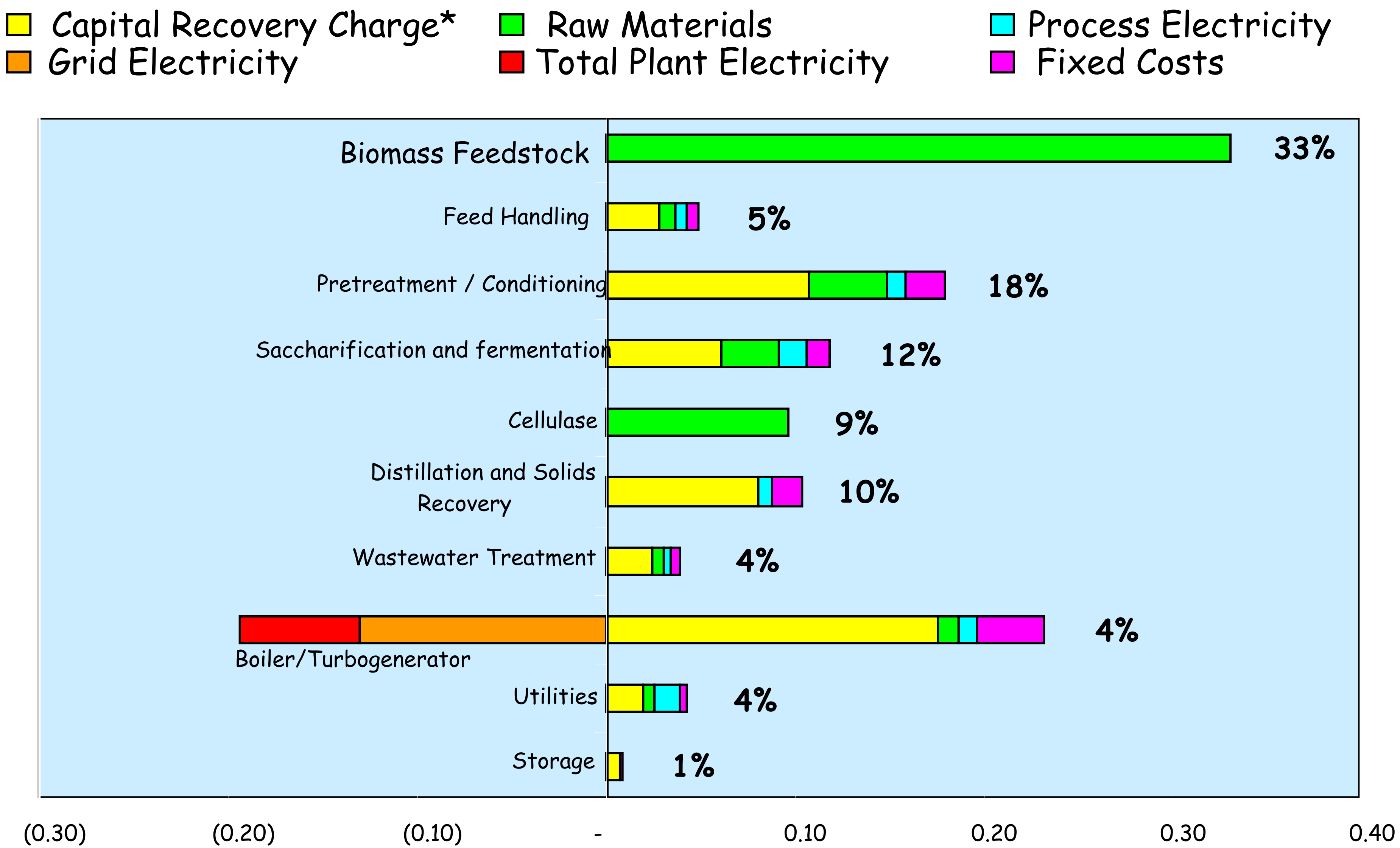
From: Billion ton Vision, DOE & USDA 2005

>1% yield is feasible

Yield of 26.5 tons/acre observed by Young & colleagues in Illinois, without irrigation

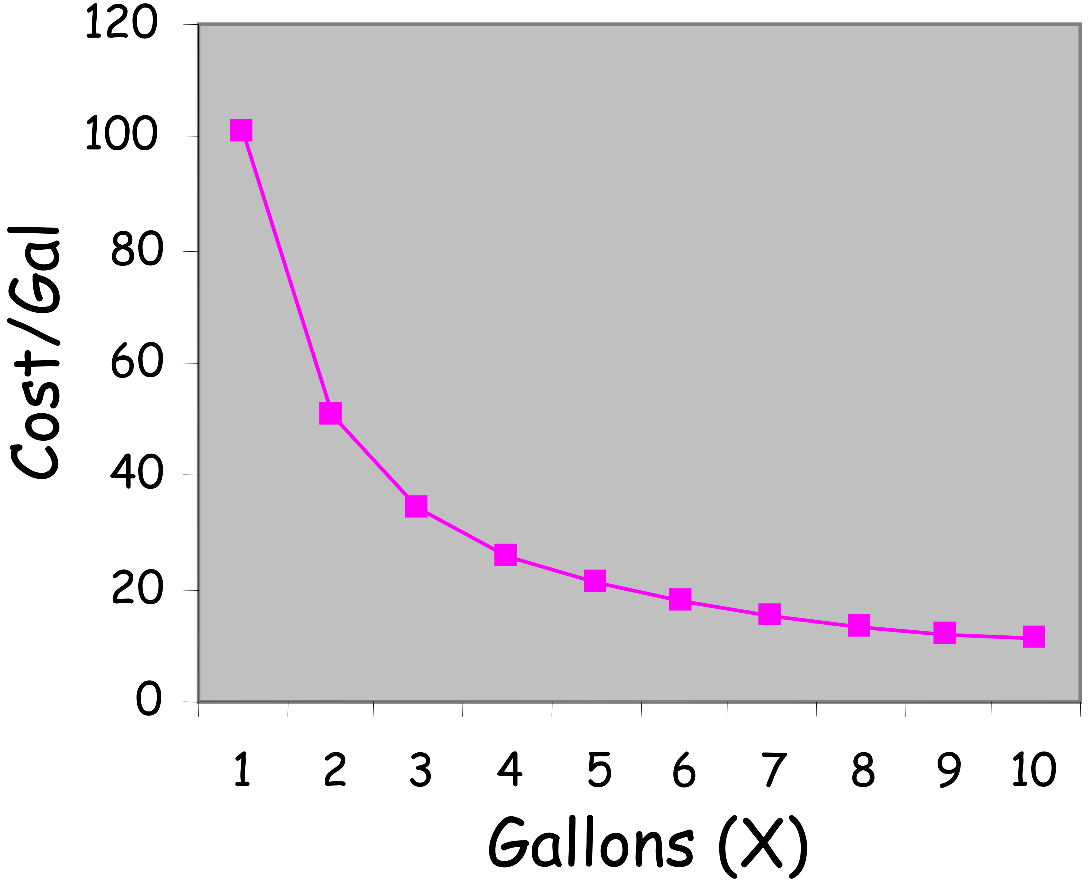
Courtesy of Steve Long et al

Relative cost factors of cellulosic ethanol



NREL Analysis

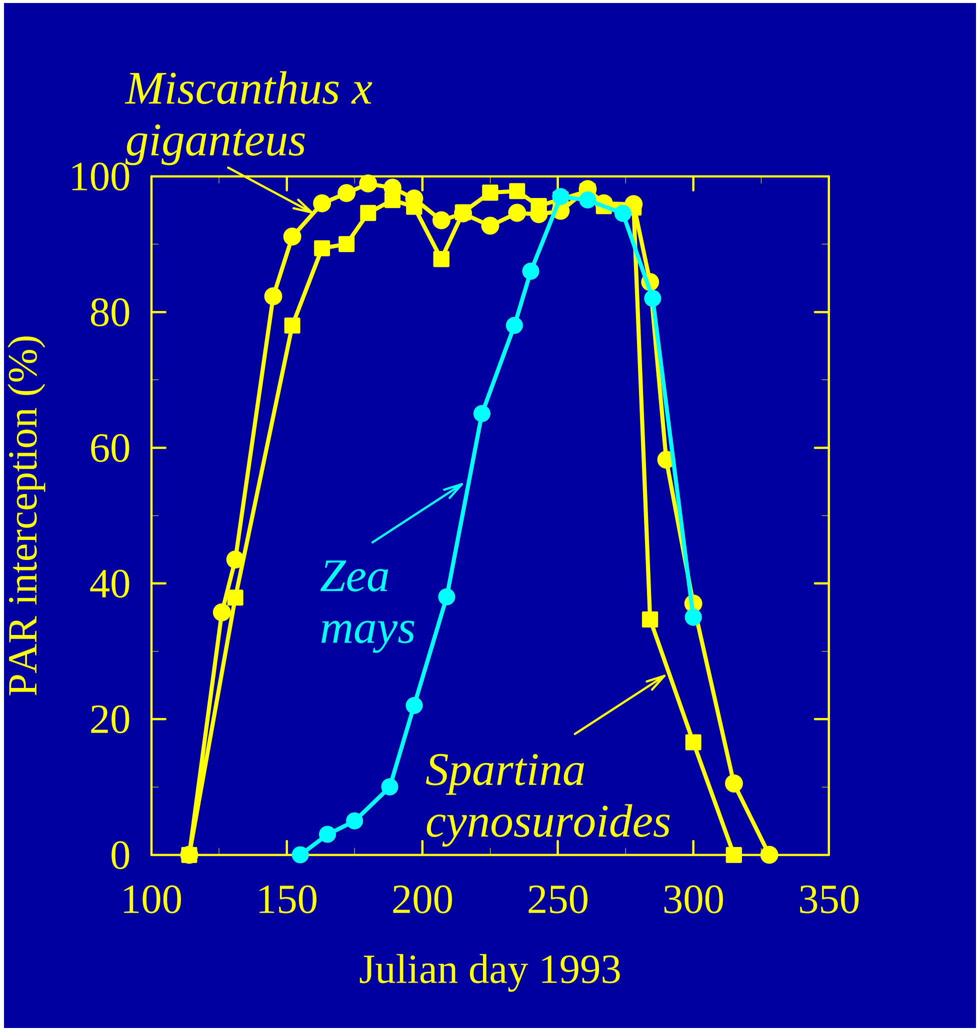
Plot of Cost/gal = (Y + aX)/X



At 15 t/a, 300 Mgal ~ 30% of all land in 20 mile radius

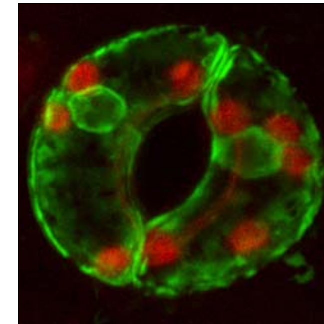
1 mi x 0.5 mi x 35 ft

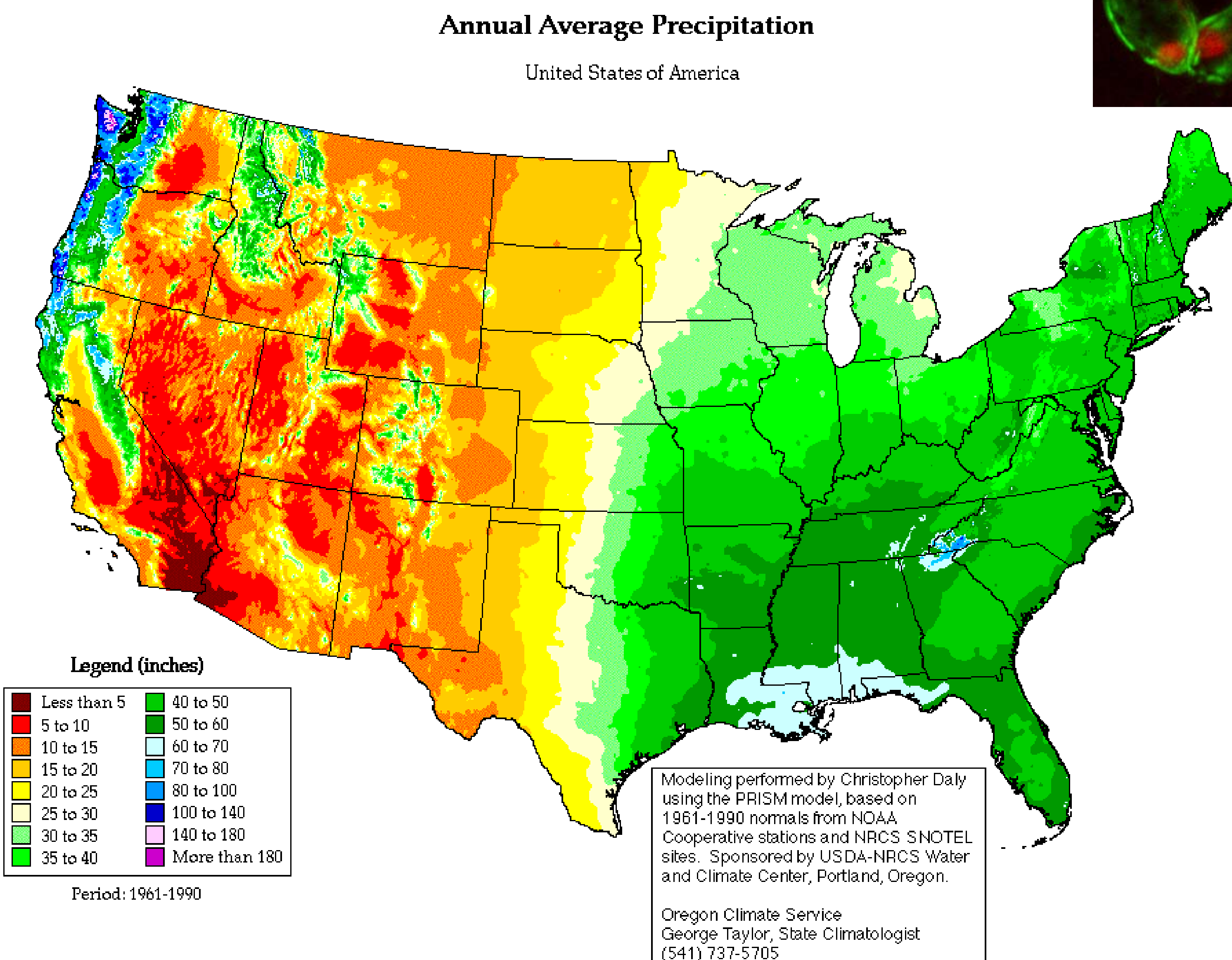
Perennials have more photosynthesis



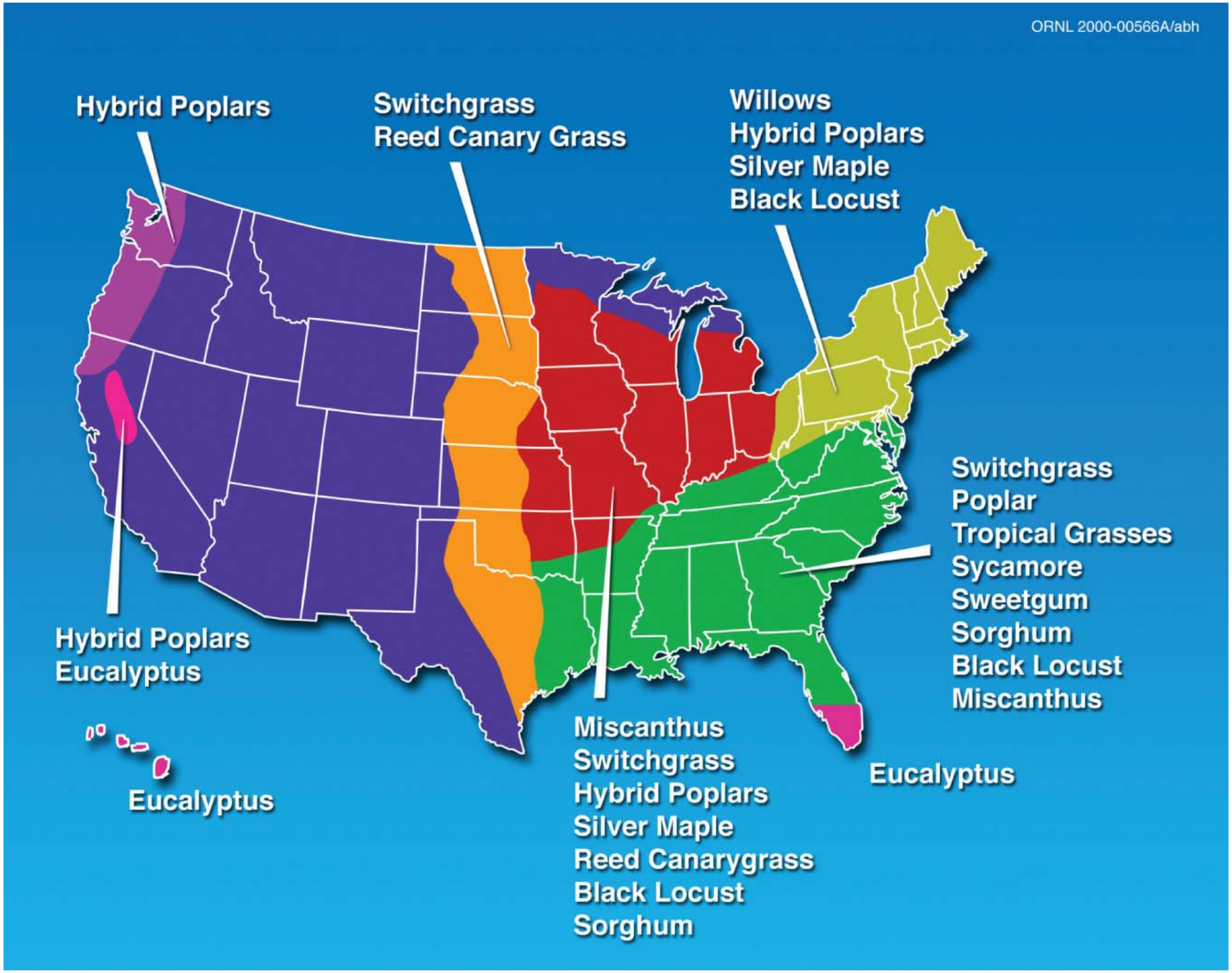
Courtesy of Steve Long, University of Illinois

Annual precipitation





Geographic distribution of biomass



Wright et al DOE-ORNL-EERE

Economics of Perennials are Favorable

CROP	Yield per Acre	Value $ @$50/t	Cost $	Profit $
Corn	160 bu	500	193*	307
Switchgrass	10 tons	500	138**	362
Miscanthus	15 tons	750	193	557

*USDA economic research service 2004
**50% as much fertilizer, no chemicals

Prospective energy crops have not been subject to intensive breeding

Miscanthus sp.

Switchgrass (Panicum virgatum)

Courtesy of Steve Long & Emily Heaton. USDA-NRCS PLANTS Database / Hitchcock, A.S. (rev. A. Chase). 1950. *Manual of the grasses of the United States*. USDA Misc. Publ. No. 200. Washington, DC.

Advantages of perennials

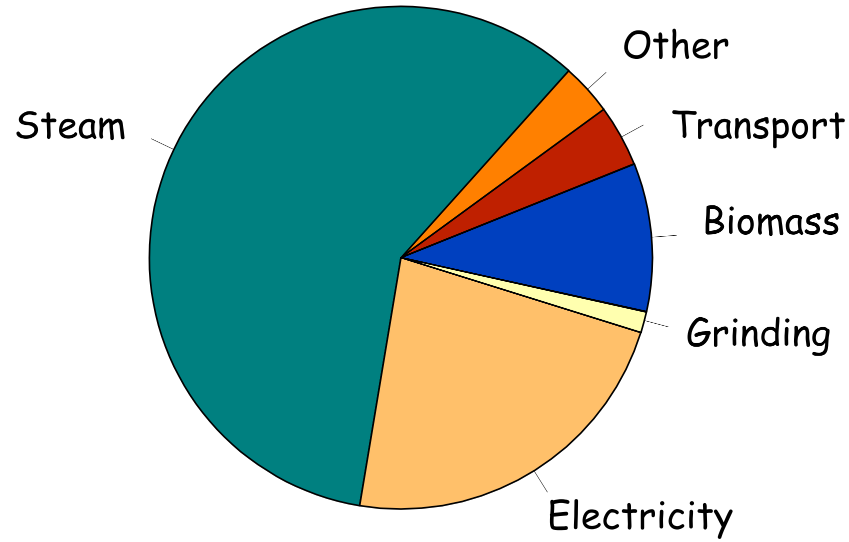
- Energy crops are expected to be more environmentally benign than production agriculture
  - Low fertilizer and chemical inputs
  - Late-harvest supports biodiversity
  - Mixed cultures possible
  - Many species can be used

Challenges in developing energy crops

- Self-incompatibility creates challenges in breeding
- Difficult to capture adequate value from seed production
- Large capital costs in building cellulosic ethanol plants will require long-term contracts

The challenge is efficient conversion

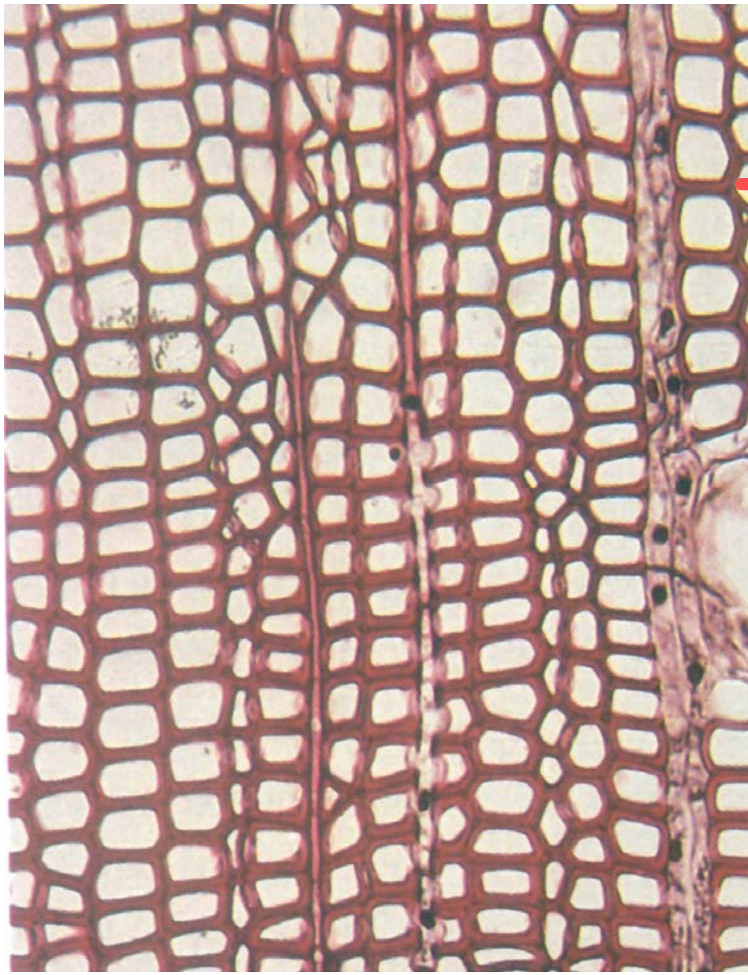
- Burning switchgrass (10 t/ha) yields 14.6-fold more energy than input to produce*
- But, converting switchgrass to ethanol calculated to consume 45% more energy than produced



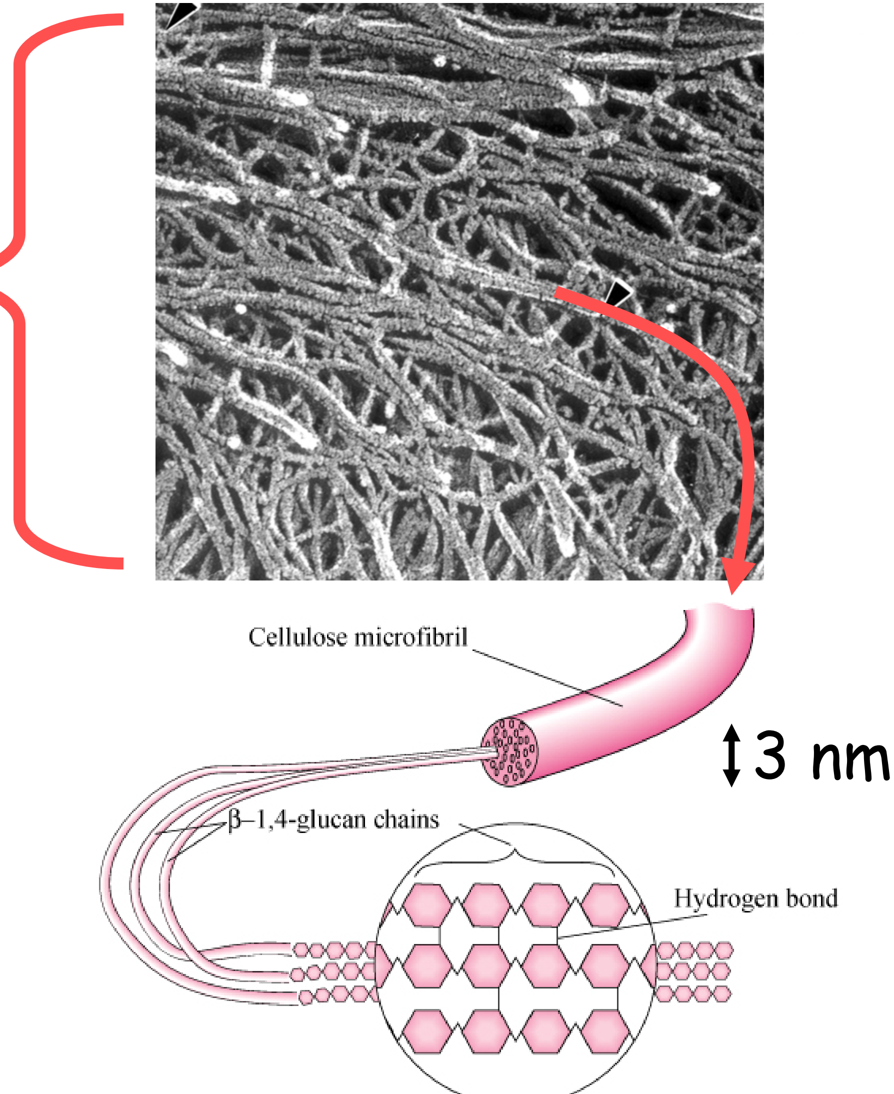
Energy consumption

*Pimentel & Patzek, Nat Res Res 14,65 (2005)

Plants are mostly composed of sugars

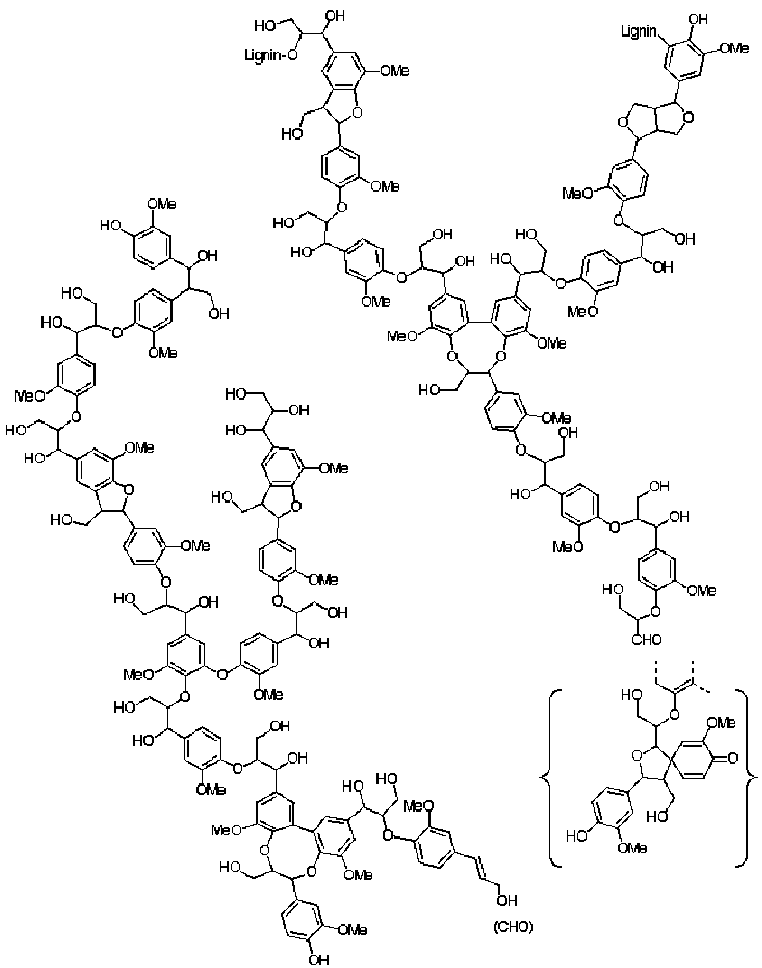


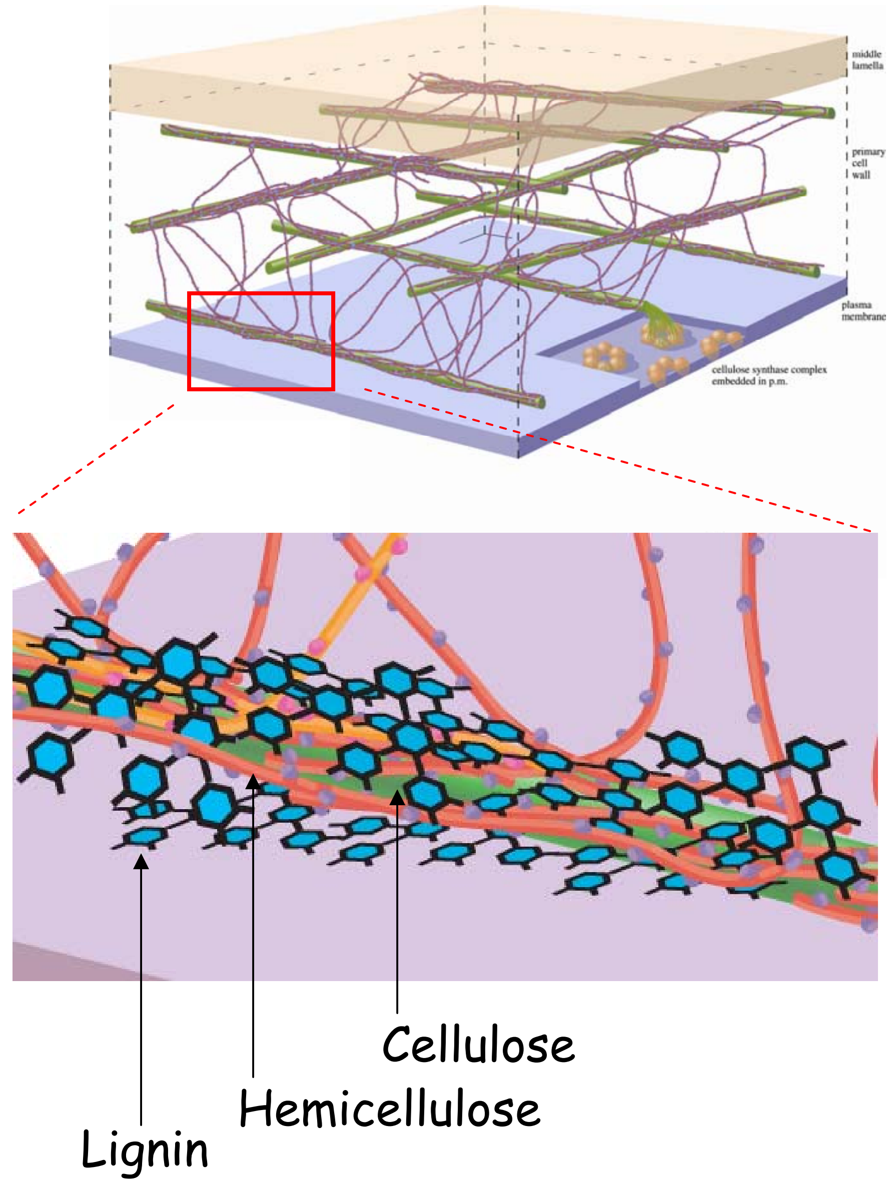
Section of a pine board



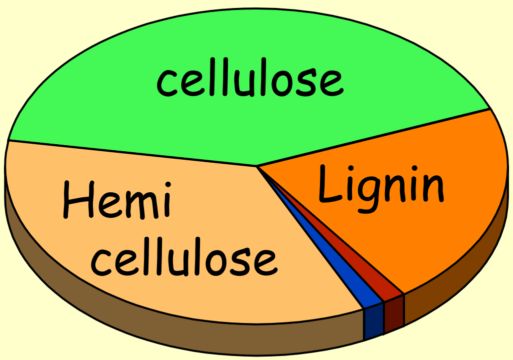
Polymerized glucose

Lignin occludes polysaccharides

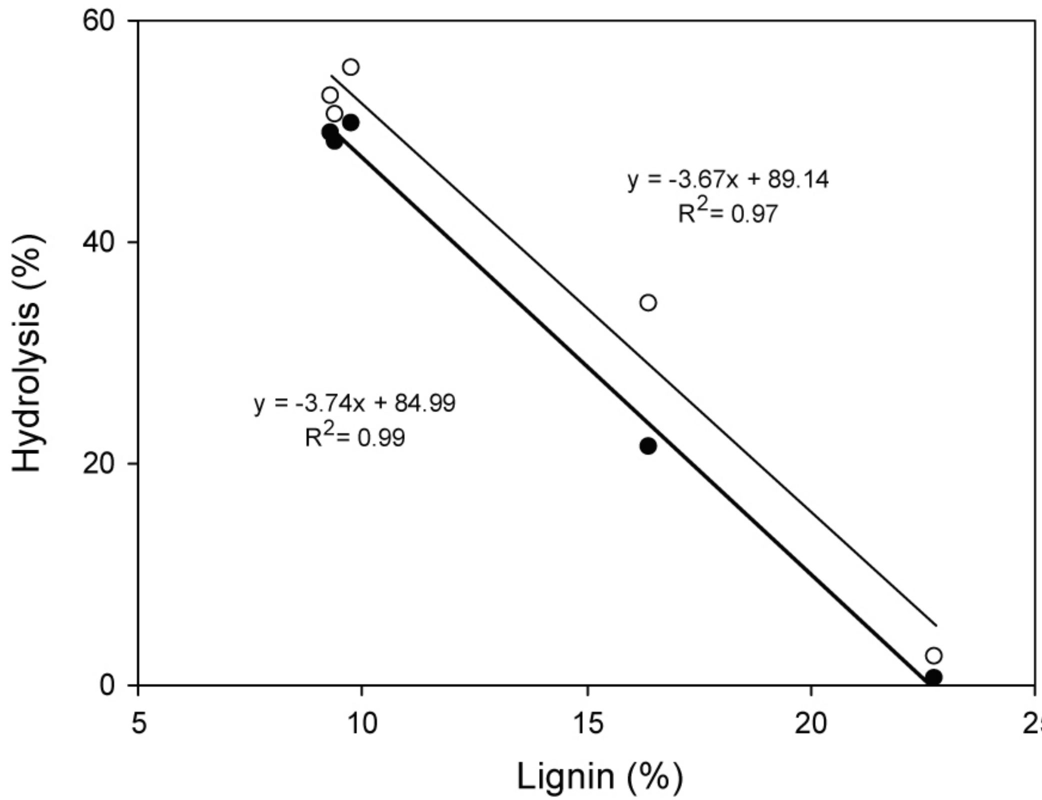




Effect of lignin content on enzymatic recovery of sugars from Miscanthus

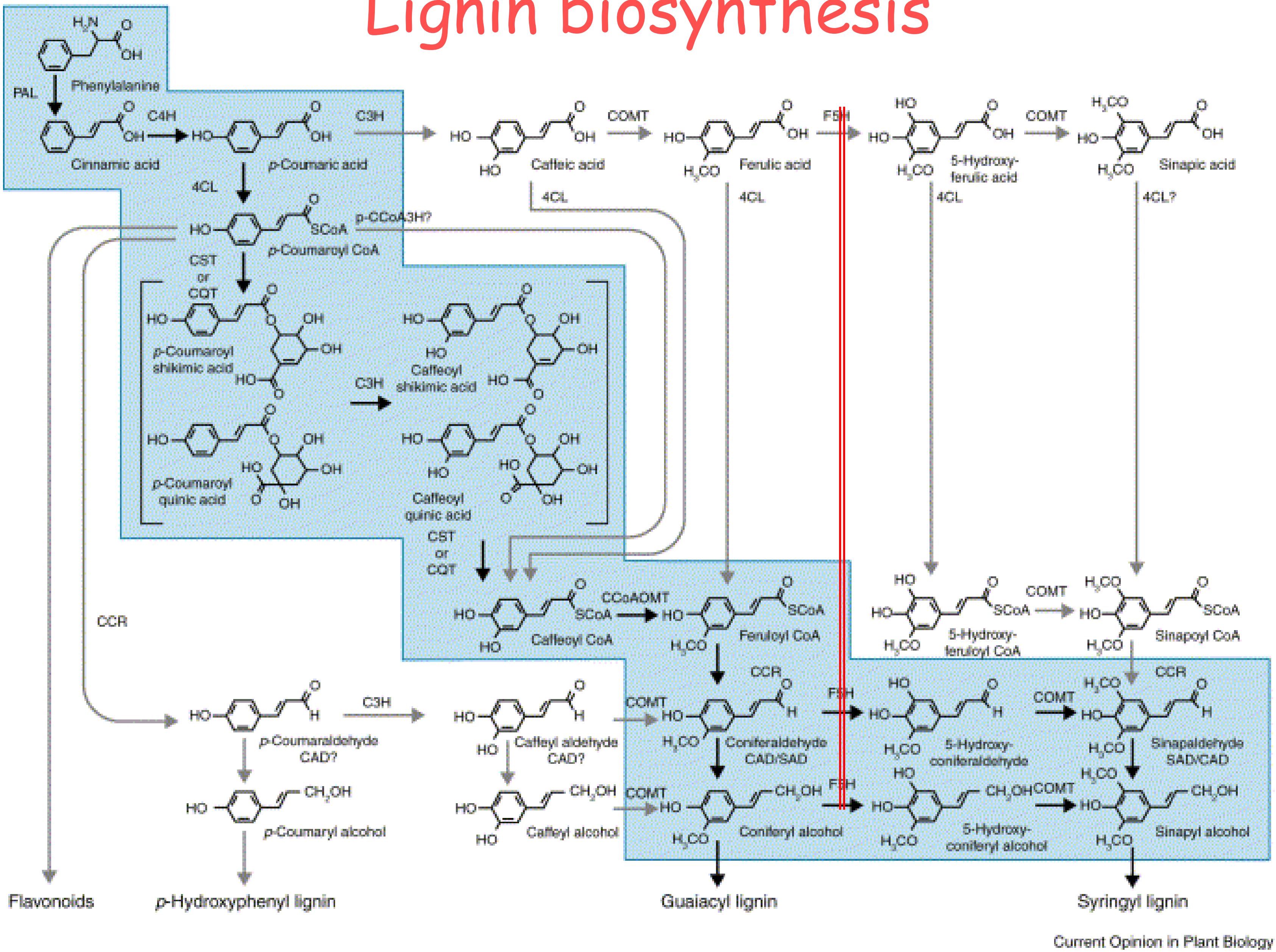


Typical grass composition



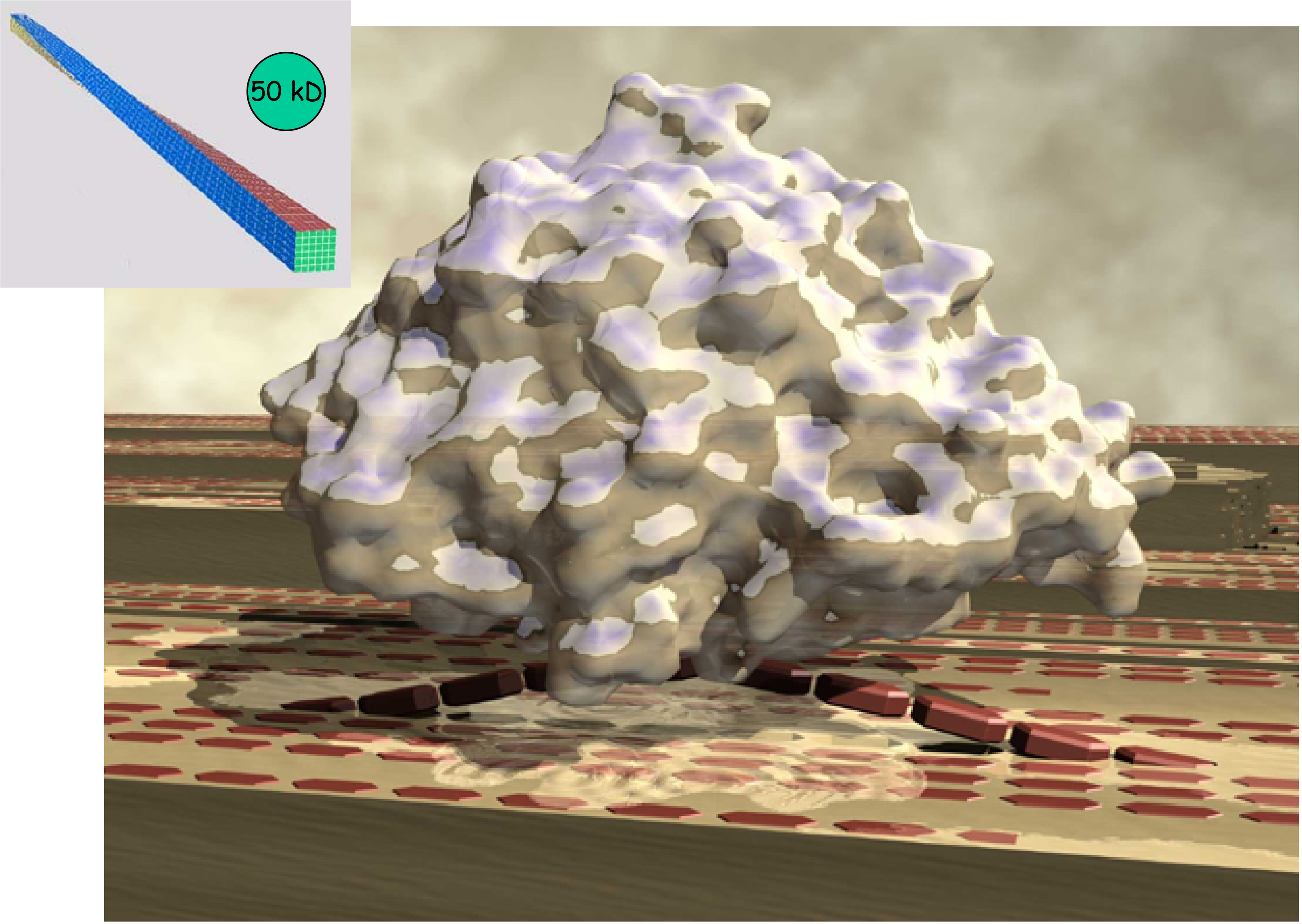
D Vrije et al (2002) Int J Hydrogen Energy 27,1381

Lignin biosynthesis



Humphreys and Chapple, Curr Opin Plant Biol 5,224

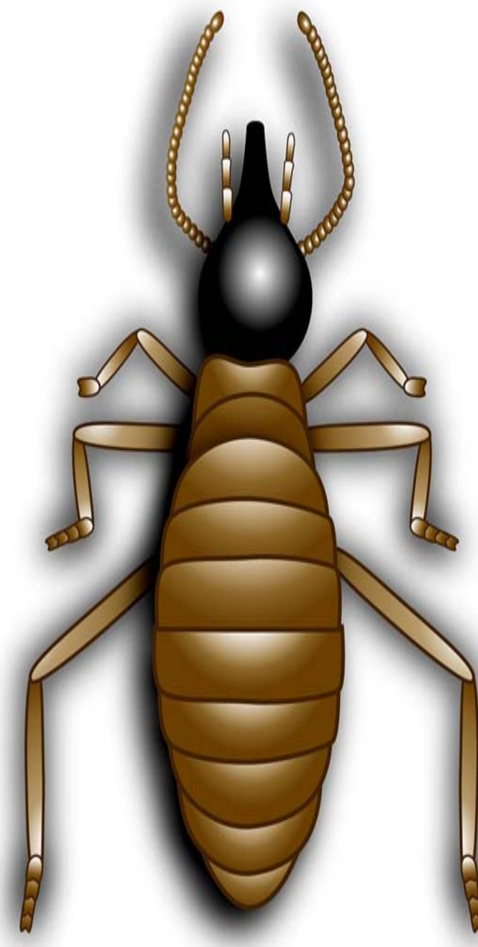
Cellulose is recalcitrant to hydrolysis



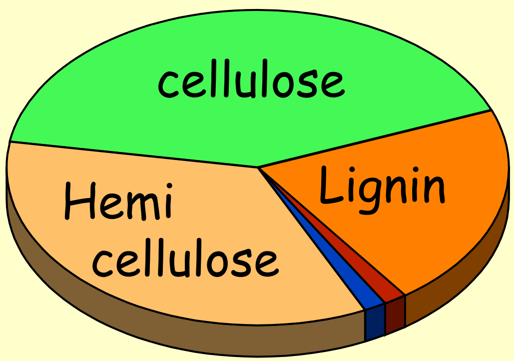
NREL

Possible routes to improved catalysts

- Explore the enzyme systems used by termites (and ruminants) for digesting lignocellulosic material
- Compost heaps and forest floors are poorly explored
- In vitro protein engineering of promising enzymes
- Develop synthetic organic catalysts (for polysaccharides and lignin)



Fermentation of all sugars is essential



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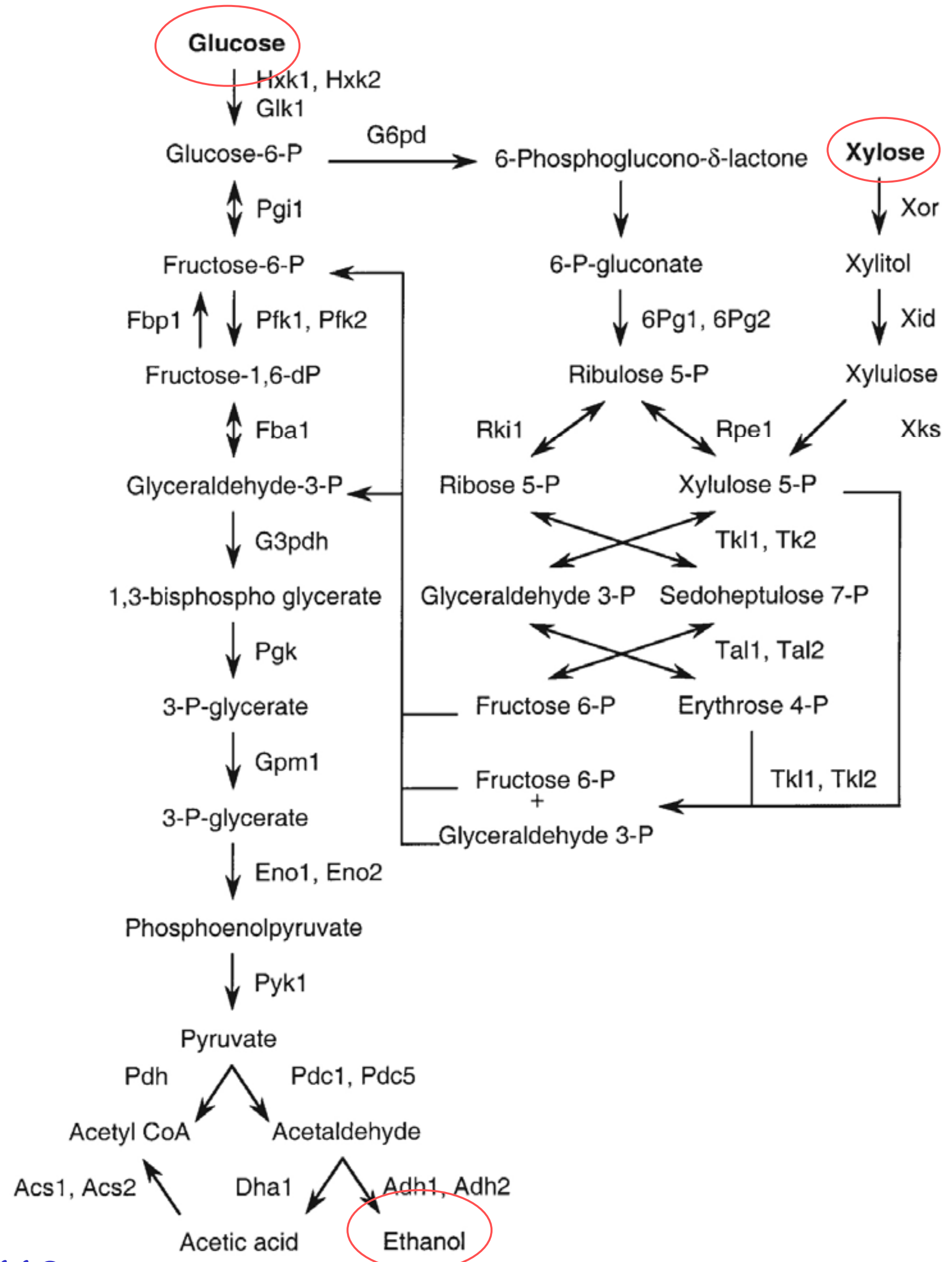


Jeffries & Shi Adv Bioch Eng 65,118

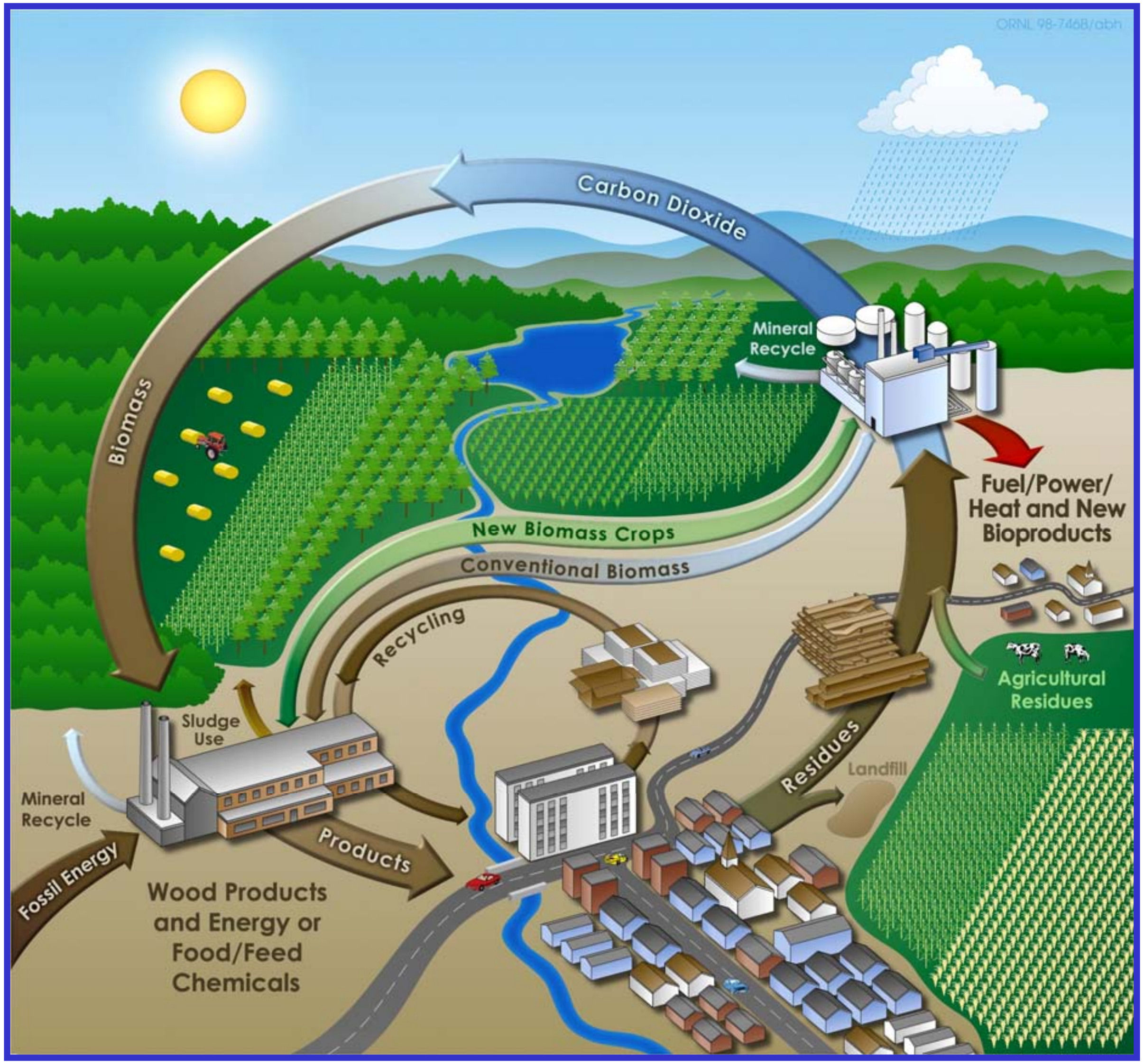
Conclusions

- Biofuels are expected be an important part of a carbon neutral energy economy
- There are no insurmountable problems
- Many improvements are possible
- The revolution in mechanistic biology offers enormous untapped potential to make fundamental changes in solar harvesting with plants

The Energy Bioscience Institute

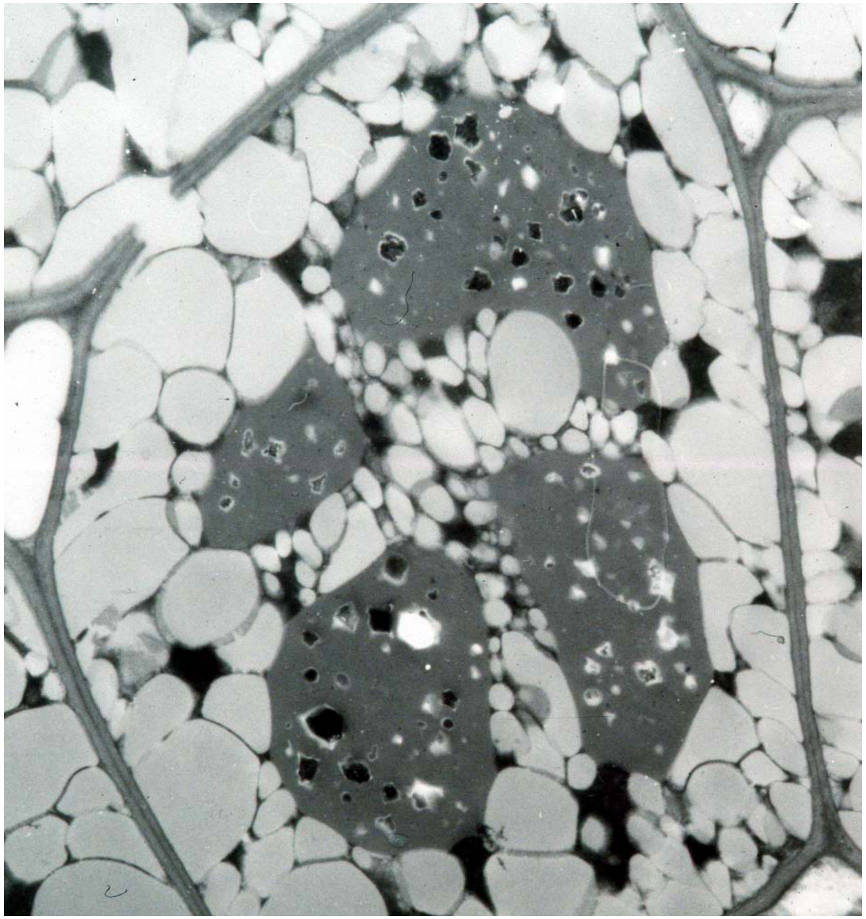
- Partnership between UCB, UI, LBL
- BP has committed $500M over 10 years
- Goals include elimination of bottlenecks to biofuels, development of improved biotechnologies for fuel production, and education of scientists and engineers across the relevant disciplines

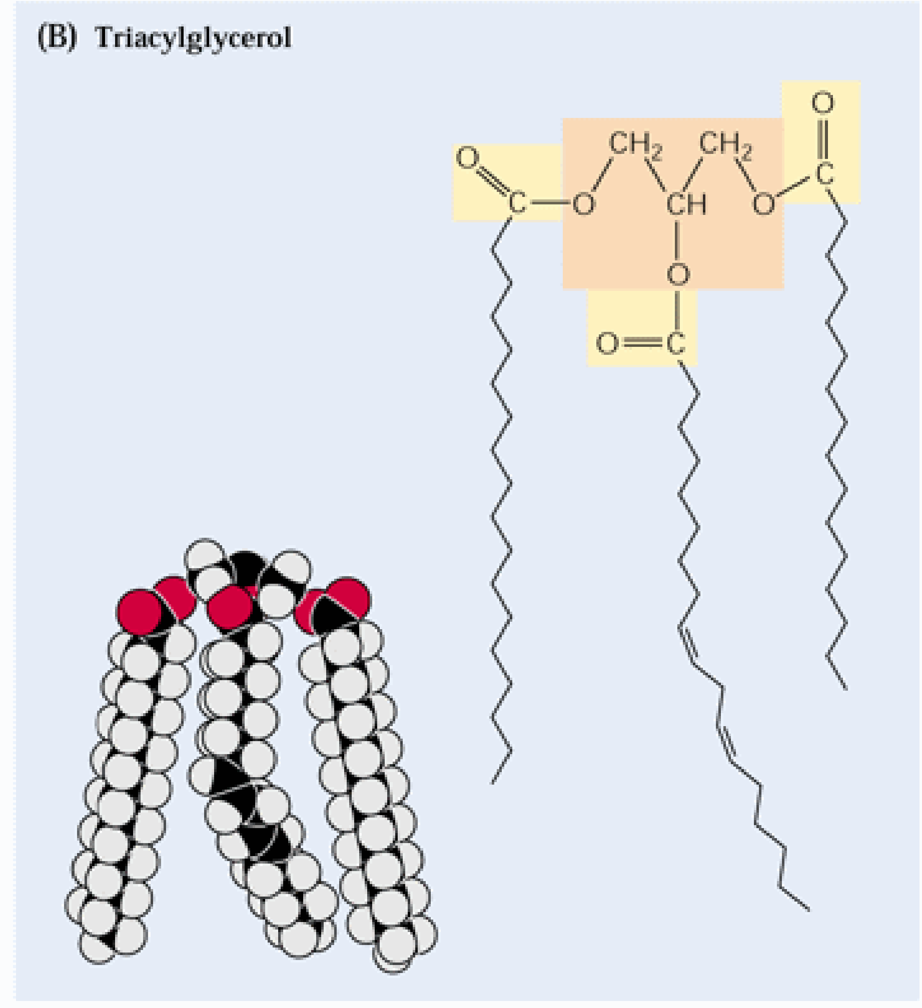
A vision of the Future



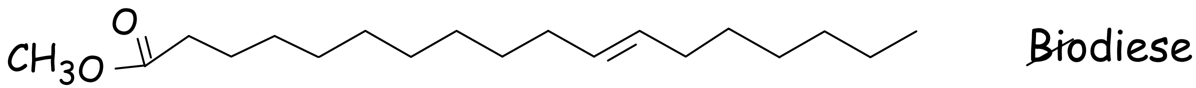
http://genomicsgtl.energy.gov/biofuels/index.shtml

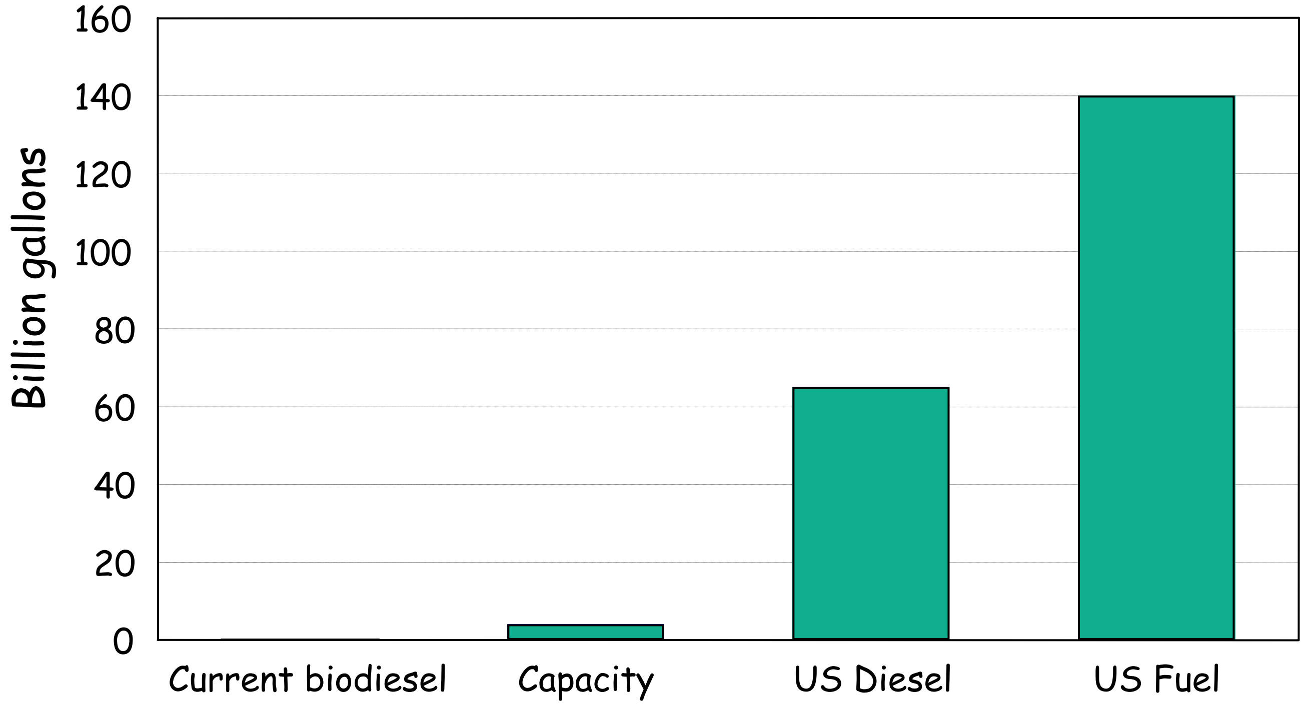
Some plants accumulate oil





Limited potential of biodiesel





65 biodiesel companies in operation, 50 in construction 2006